

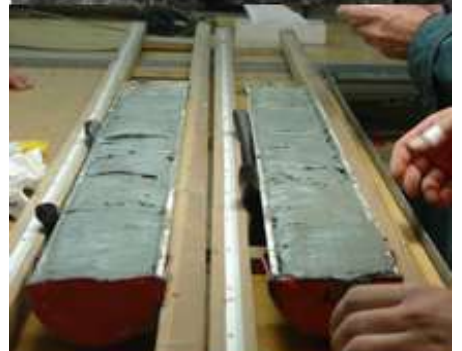
A Synthesis of Analytical Methods Applied to Sediment Cores from the ANDRILL Southern McMurdo Sound Project.

Abstract

Geologic records of past environmental variability are necessary to reliably project climatic conditions in the future. Climate changes in Antarctica and its role in global systems, remains poorly understood. ANDRILL's objective is to develop more detailed records of past climatic changes in the Ross Sea Region, including responses to glacial advance and retreat. The analysis of ANDRILL core in the Southern Ross Sea adopts a multi-disciplinary approach. Investigations include sedimentology and stratigraphy, palaeontology, geochemistry and petrology, paleomagnetism, and chronostratigraphy and geochronology. Methods used under each of these disciplines are explored in terms of the significance of investigation and how data acquisition is carried out.

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1 Introduction

The ANtarctic geological DRILLing program (ANDRILL) adopts a multi-disciplinary approach to the way scientific procedures and investigations are carried out on sediment core in order to gain quantifying results (Florindo *et al.*, 2009). Sediment cores of the Antarctic continental margin represent a sample of geological history fundamental in understanding “Antarctica’s storied past” (Naish *et al.*, 2007).

ANDRILL’s main objective is to drill stratigraphic cores for the use of interpreting a history of paleoenvironmental changes of the Ross Ice Shelf spanning back the last 50 million years. The main motivation driving this comes from the need to better understand more about the complex roles the Antarctic cryosphere has played in the global climate system in the past (Rack *et al.*, 2007). Through establishing a robust history of this, better understanding of Antarctica’s role in the future global system can be gained. This understanding is necessary when making predictions about future scenarios of global warming and climate change (Harwood *et al.*, 2005).

This paper presents a synthesis of the analytical methods involved with core analysis in the ANDRILL Southern McMurdo Sound (SMS) project. The analytical methods that have been investigated have been categorised under scientific disciplines. Review of these analytical methods will put emphasis on what is being investigated and methods involved in data analysis.

2 Paleoenvironmental Change and Reconstruction

Paleoenvironmental change refers to the environmental setting and conditions of an area in a given period in time. The Antarctic margin has experienced climate fluctuations through geological history where such climatic conditions have impacted the formation of sediment layers. Paleoenvironmental changes such as glacial advance and retreat represent cyclic fluctuations between warm open water and cooler ice covered conditions (REF).

The ocean floor receives a continuous supply of small particles that settle out and form sediment deposits where sediments in core serve as a time line of events. Particles vary in size, shape, chemistry and colour and originate from many sources and environmental conditions (Boggs, 2006 and Prothero & Schwab, 1996). Conditions such as ice cover or open waters have obvious influences on the type and abundance of living organism that live in oceans and also on sediment supply, origin, environmental energy and mechanisms of deposition. Preservation of these organisms and sediments are important in distinguishing the nature of the environment in time. Through the analysis of core sediment, evidence that indicates paleoenvironmental changes such as changes in Antarctica's cryosphere can be examined.

Paleoenvironmental reconstruction refers to the investigations which are undertaken to reconstruct the climate, environmental conditions and living organisms of a specific time and place. In this literature review these investigations include sedimentology and stratigraphy, palaeontology, geochemistry and petrology, paleomagnetism and chronostratigraphy and geochronology. Emphasis will be put on the methods used under each of these disciplines and what is the significance and area of focus for each methods used.

3 Areas of analysis and methods

3.1 Sedimentology and stratigraphy

Sedimentology is the interpretation of past environmental conditions. It is achieved by examining the constituents, textures, structures, and fossil content of a deposit where stratigraphy is based on the relationship between successive rock layers (Boggs, 2006). Sedimentological investigations include lithostratigraphy and facies analysis. Lithostratigraphy deals with the lithology and their organisation into units and facies analysis is the classification of depositional clues and environmental interpretation. Stratigraphy is recognised by the stacking of unconformable-bounded units, for instance of ANDRILL core SMS times of glacial retreats, transgression and sea-level highstand.

Core description and construction of core logs

The main aim of core characterisation is to provide a detailed and comprehensive description of the core that can be interpreted in terms of Paleoenvironment to provide a summary description of the core that can be used in other disciplines of analysis (Florindo *et al.*, 2009). Core logs are a visual representation constructed by recording lithostratigraphic units based on minor and major changes in lithology and lithofacies are reviewed for depositional environments against the depth of core recovered. Patterns are used to represent lithologies and symbols for physical and biogenic sedimentary structures, deformational structures, contained fossils and bed contacts (Fielding *et al.*, 2008). A palaeontological stratigraphic interval construction and analysis tool was used to record and construct a stratigraphic log. This is a graphical editing tool designed to support the core description process from the initial data capture, to visualization, to data analysis stages (Reed *et al.*, 2007). This technology was successfully tested for the first time on the ANDRILL McMurdo Ice Shelf program (Krissek *et al.*, 2007).

Core Imagery

Core imagery is used to capture representative digital images of lithofacies, bed and unit contacts and other features of significance (Florindo *et al.*, 2009). A core scanner scans operates by taking still images of the entire 360 degree surface while it rotates. This

provides a flat picture of the core so analysis of the orientation, origin and mode of the fractures can be made (Florindo et al., 2009). This is a useful method that can allow faster analysis of the core by the ability to distribute data more readily and allows for a good achievable record to be made (ANDRILL, 2010).

3.2 Palaeontological characterisation

Palaeontology is the study of pre-historic fossil organisms. Their evolution in time, age and environment in which they inhabited are of great importance (Crowen, 2005). Fossils are of fundamental importance in interpretation of Antarctic sediments in terms of environmental reconstruction, sedimentary processes, chronology and climate (Florindo *et al.*, 2009). Palaeological characterisation is an analytical method that concerns this. Their analysis contributes towards biostratigraphy which focuses on depths of the age of diagnostic fossils and biostratigraphic events. For the ANDRILL SMS core identifications and characterisations were made on the following fossil groups. Diatom and Foraminifera methods of characterisation are developed further below in this synthesis as antarctic marine microfauna and microflora are strongly dominated by diatoms and foraminifera were more significant in late Cenozoic Antarctic sediments (Florindo *et al.*, 2009).

Diatom analysis and other siliceous microfossiles

Diatom is a single celled silicate body that can be preserved within a sediment record. Diatoms are the primary palaeontologic tool for biostratigraphy and palaeoenvironmental reconstruction for the Antarctic as their character indicates whether they are marine or glacial in origin (Florindo et al., 2009 and Stickly *et al.*, 2007). Analysis is carried out from samples on smear slides at 1 metre increments using a transmitted light microscope where diatom identification and abundance assessments are made. Abundance is categorised using a value classification scheme determining abundant, common, few, rare, present and barren (Taviani *et al.*, 2009). When identifying specimens of diatoms the removal of excess material by flushing and sieving is completed. This allows for a more complete account.

Foraminiferal Micropaleontology

Foraminiferal are single cell protozoans that exist in many forms, environments and compositions (calcareous and agglutinated). Foraminifera are also reliable marine

indicators and assemblages are useful to interpret paleoenvironmental conditions such as bathymetry, salinity, temperature, and organism productivity (Boggs, 2006). Benthic foraminifera combined with diatom data can provide good stratigraphic control. Analysis is conducted by statistically differentiating assemblages to define assemblage zones within the core for biostratigraphic purposes (Florindo et al., 2009). Samples are taken in sets, then washed which removes residues then samples of foraminifera are weighed (Taviani *et al.*, 2009). The presence and absence of foraminifera are noted on a criteria of very rare, rare, common and abundant (Taviani *et al.*, 2009). Foraminifera are then picked for further classification analysis. Depending on circumstances calcareous forams maybe also targeted as dateable material .

Marine and Terrestrial Organic Walled Fossils- Polymorphs are analysed and characterised in being marine or terrestrial in origin. The principle palynological residue in most samples comprises of coal. Counts are taken to determine abundance.

Terrestrial Lignin-Rich Organic Matter – The study of carbonaceous microorganisms, including pollen spores. Analysis is focused on characterisation and significant shifts in assemblages which can reflect environmental change such as glacial advance and retreat (Florindo et al., 2009).

Macrofossils - Bodies of calcareous macrofossils and traces may be locally abundant and diverse, dominated by benthic molluscs such as bivalves and gastropods, and bryozoans, barnacles, echinoderms and other groups (Taviani *et al.*, 2009).

3.3 Geochemistry and Petrology

Geochemistry investigates the chemical composition of sediment samples to accurately determine composition of a rock and indication of processes and reactions undertaken. Petrology involves synthesizing rocks to determining the chemical and physical conditions under which sediments and rocks form. Both geochemical and petrological analysis is important when re-constructing the mode of emplacement and post-depositional history of the deposits (Florindo *et al.*, 2009). The main focus for the SMS core for geochemical and petrographical analysis is to investigate compositional and textural characterisation of coarse glacial sediments and the description and characterisation of volcanic layers and

tephra (Florindo *et al.*, 2009). Analysis of clast and sand petrology within the SMS core have provided information of probable local and distal sources that correspond to variable ice-volume and ice flow directions (Panter *et al.*, 2008).

Clastology

This is an in-situ macroscopic, fore face analysis of all clasts that range from granule to boulder grain class in size. Clast counts were performed per 1 metre and per 10 centimetre intervals, where for each clast, information such as composition, dimension, shape and surface features were collected. This information was added to the core log by inputting it into the palaeontological stratigraphic interval construction and analysis tool. These clast counts are then represented next to the lithostatic intervals on the core log. For clasts larger than 1cm these were logged using a software called Corelyzer (Panter *et al.*, 2008).

Petrographical examination

Petrographical analyses were performed through thin-sections where qualitative estimates were made by optical microscopy (Panter *et al.*, 2008). This analysis takes into account the mineralogical components such as composition and mineral chemistry and petrographical textural features such as grading, internal sedimentary structures, grain size, internal organisation and geometry (Winter, 2001.) Thin-section sections were taken in every 1 metre interval and additional samples were taken where lithologies appeared likely to provide optimal dateable material to ensure optimal correlation between results (Panter *et al.*, 2008). An advantage of thin sections analysis can help to discriminate between different lithologies and to improve lithological determinations originally made with the core logging and descriptions (Florindo *et al.*, 2010). A disadvantage however, can occur with fine-grained units where they are likely to be unable to be examined by typical microscope techniques. This can be due to lack of coverage samples contain or the general size of sample. This is usually resolved undertaking XRF analysis (Florindo *et al.*, 2009 and Winter, 2010).

XRF –X-ray fluorescence core scanning

X-ray fluorescence (XRF) is a well-established analytical technique for estimating the compositional characterisation of bulk sediments. Its advantage is it allows non-destructive,

quick extraction of near continuous records of element intensities from sediments within the core where analysis allows for a high resolution geochemical dataset (Panter *et al.*, 2008 and Welje & Tjallingii, 2008). This is undertaken at the initial stage of core retrieval on the archive face once the core is split. The core scanner measures the variation in elements of atomic mass range from Al (atomic no. 13) to U (atomic no. 92). The operation of the scanner is by an X-ray source, which travels through a He-flushed prism where it hits the sediment surface at 45 degrees. The detector for the outgoing fluorescence radiation is also orientated at the same angle. A foil cover applied to the sediment surface during this process avoids contamination of the core. Resolution is in the order of 1 and 10 centimetres (Florindo *et al.*, 2009 and Panter *et al.*, 2008). A disadvantage relative to conventional geochemical analysis is the problematic conversion of core-scanner output to element concentrations (Welje & Tjallingii, 2008). Irregularities of the split core surface such as large clasts, fractures and veins can also hinder results and therefore core section is checked by hand to prevent measurements of these (Florindo *et al.*, 2009).

XRF – X-ray fluorescence single sample analysis.

XRF is applied to fused single whole rock samples to determine geochemical nature. One-metre intervals of rock samples from the core undertook XRF single sample analysis. The process includes freeze drying and crushing where samples larger than 2mm are removed. The water content is able to be calculated by weighing before and after freeze-drying (Panter *et al.*, 2008). The powder produced by crushing is analysed by the XRF for element results. These results were then used for corrections and calibration of the XRF core scanner undertaken and used to expand existing geochemical data set (Panter *et al.*, 2008).

3.4 Paleomagnetism

Palaeomagnetic record of the core is examined with a primary focus on determining a preliminary magnetostratigraphy, which can be used to assist in dating the stratigraphic section (Action, Florindo *et al.*, 2009). Magnetostratigraphy is a chronostratigraphic technique used to date sedimentary and volcanic sequences.

Samples were collected from split core sections. Orientated samples were collected where possible from fine-grained undistributed horizons every one to two metres along the core

for paleomagnetism analysis. Paired samples with already stratigraphically analysed samples were taken every 10-20 metres. Sample retrieval is done by taking mini core samples with a drill press where each sample was 2.3 cm in diameter and 4.2 cm in length. During the collection and handling phase particular caution is made to not expose samples to strong magnetic fields (Action Florindo *et al.*, 2009).

Magnetic susceptibility

Magnetic susceptibility is the degree of magnetisation of a material in response to an applied magnetic field. High and low magnetic susceptibility are measured using a Bartington MS2 susceptibility meter. Clasts sampled for petrological work were also sampled for this (Florindo *et al.*, 2009). A limitation for this analysis is once the core is split degradation occurs and data is lost due to oxidation. It is ensured that immediate magnetic susceptibility measurements are made when samples are collected.

Magnetometers

Magnetometers are used to determine the magnetic polarity of natural remnant magnetisation in samples. This is completed using magnetometers which are stored in magnetically shielded rooms (Florindo *et al.*, 2009).

3.5 Chronostratigraphic and Geochronology

The aim of chronostratigraphic data is to pull together and integrate all age information available and define and delineate on the basis of geologic time units. Age models are then produced that incorporates data from biostratigraphy and magnetostratigraphy studies, radiostratigraphic dating of volcanoclastic sediments and tephras, $^{87}\text{Sr}/^{86}\text{Sr}$ dating of micro and macrofossils, and correlation of compositional and physical properties to well-dated global or regional records (Acton *et al.*, 2009). Age model provides a basis for studying the timing and rates of geologic, climatic and tectonic events recovered in the core, and for the comparing of them with other records from around the world (Boggs, 2006). Geochronology analysis determines the absolute age of a rock through dating methods such as ^{40}Ar - ^{39}Ar Geochronology and Sr-Isotope Dating.

^{40}Ar - ^{39}Ar Geochronology

Argon dating, ^{40}Ar - ^{39}Ar geochronology determines radioisotopic age. Samples are mainly volcanic clasts embedded in diamictite. This analysis relies on the state of preservation of clasts together with the presence in diamictite conditions. This allows good age correlation to be undertaken. Samples have included breccias, lava clasts and ash layers with potassium-rich feldspar crystals (Acton *et al.*, 2009). Initially samples selected are examined to determine sufficient material for ^{40}Ar - ^{39}Ar dating. Radioisotopic dating is completed using noble gas mass spectrometer using laser extraction techniques. Limitations have arisen with the core where there is significant sections with no dateable material. Analytical errors include, uncertainties in neutron fluence, monitor age and ^{40}Ar decay constants (Acton *et al.*, 2009).

Sr-Isotope Dating

Strontium dating, $^{87}\text{Sr}/^{86}\text{Sr}$, acquires elemental ratios (Mg/Ca, Sr/Ca, Mn/Ca and Fe/Ca) using a Thermo Fisher Finnigan Element conductivity coupled plasma-mass spectrometer to determine a half life ratio (Acton *et al.*, 2009). Strontium has four stable, naturally occurring isotopes. ^{87}Sr is radiogenic; it is produced by decay from the radioactive alkali metal ^{87}Rb , which has a half-life of 4.88×10^{10} years where ^{86}Sr formed by radioactive decay of ^{87}Rb . The ratio $^{87}\text{Sr}/^{86}\text{Sr}$ is the parameter ratios in minerals and rocks investigated (Dickens, 2005). Because strontium has an atomic radius similar to that of calcium, it readily substitutes for Ca in minerals. With the SMS core it is applied to macrofossils that displays a good state of preservation. A major limitation arises when decalcified microfossils are recovered as they are unsuitable for Sr isotopic dating. Unaltered material provide ages that coincide well with other age estimates (Acton *et al.*, 2009). The observed unaltered chemical profiles of $^{87}\text{Sr}/^{86}\text{Sr}$ ages obtained are the focus on further work to sections of core needing further age constraints (Acton *et al.*, 2009).

4 Conclusions

Analysis of the sediment core from the ANDRILL Southern McMurdo Sound is a multi-disciplinary approach. Analytical methods that are involved in data acquisition fit under sedimentology and stratigraphy, geochemistry and petrology, paleomagnetism and chronostratigraphy and geochronology. The synthesis of these methods includes the subject of investigation and the means of data collection. This review does not include the analysis methods applied down the drill hole, however should be noted as a great importance in the overall paleoenvironment examination.

Through the review of stand alone analysis it is clear information and data acquired is not satisfactory evidence in coming to sound conclusion about paleoenvironments. In many cases the results from a particular method need to be reviewed for the viability of another method to proceed. This is evident with core description analysis in order to find sufficient fossil material for palaeontology and geochronology methods. The need to integrate results from each discipline is paramount and is evident in chronostratigraphy and producing finalised stratigraphic logs. This aids scientist ability in piecing together a paleoenvironmental history that is critical in understanding the role ice shelves have in the global climate system and the influence they may have in years to come.

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